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National Synchrotron Light Source II

the first year of user operations

groundbreaking

state-of-the-art

world-leading



This is the National Synchrotron Light Source II.

In its first year of user operations, scientists and engineers at NSLS-II have pushed the boundaries of synchrotron science, testing the limits of possibility and opening the doors to researchers from laboratories and universities around the world.

They come for the brilliance of the X-ray beams, which enables frontier science and cutting-edge innovations: the exploration of new energy materials and structural analysis for the creation of better batteries, catalysts, and fuel cells; developments in biochemistry and protein crystallography that lead to improved drug design; and a nanoscale examination of our environment, our planet, and even interstellar dust.

They come for the expertise of staff scientists and technological innovations, which position NSLS-II as a leader for the coming generation. They come to be a part of the future of science.

It is the brightest synchrotron light source in the world. It is a user facility fostering discoveries and creating breakthroughs critical to achieving the mission of the U.S. Department of Energy and to meeting the challenges facing our nation. This is the National Synchrotron Light Source II.

Powering the Machine



At the heart of NSLS-II are the accelerators, the injector, and storage ring systems that are the birthplace and delivery mechanism for the electron beams that ultimately produce X-rays used in a variety of scientific applications.

In the first year of user operations, the NSLS-II Accelerator Division provided stable beam for users while also commissioning 7 new beamlines, installing the second superconducting radio frequency cavity, and steadily pushing the machine to operate at higher beam currents, ultimately aiming to fulfill the design capabilities of storing 500 milliamps of current.

By April of 2016, NSLS-II was routinely delivering 250 milliamps of current in the storage ring, more than doubling the beam current available when the first users arrived in July 2015. The Accelerator Division has pursued an aggressive schedule for ramping up current in the storage ring, testing accelerator performance at 400 milliamps during beam studies in February 2016.

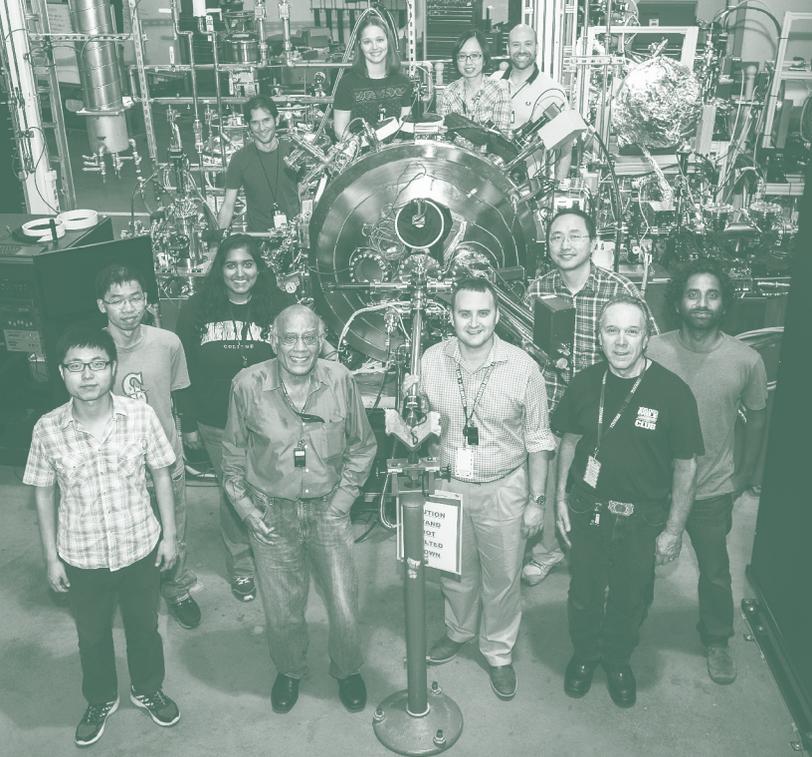
Over the past year, the stability and reliability of the machine have improved enormously. In October 2015, the Top Off Safety System began operations. A sign of the state-of-the-art offerings at NSLS-II, Top Off allows for quasi-continuous beam to be made available to users, keeping

the beam current constant and minimizing changes in thermal load to beamline optics. Top Off injections take place every 2 to 3 minutes, keeping the beam steady. Beam current does not change by more than 1 percent during routine operations. The longest stretch of operations with continuous beam was 3 days over the July 4, 2016 holiday weekend.

Reliability of the beam for fiscal year 2016 was 91.4 percent, and reproducibility of operations is stellar at NSLS-II. On restarting the machine after maintenance shutdowns, the Accelerator Division has found no issues and can quickly bring the facility up to full operations in a matter of hours.

NSLS-II provides beams of light with extremely small spot sizes while achieving the brightest synchrotron X-rays and the lowest electron emittance in the world. This is new, unexplored territory, and the Accelerator Division has been dedicated and agile when overcoming unexpected challenges to provide the best user experience for every scientist who visits NSLS-II.

unexplored territory



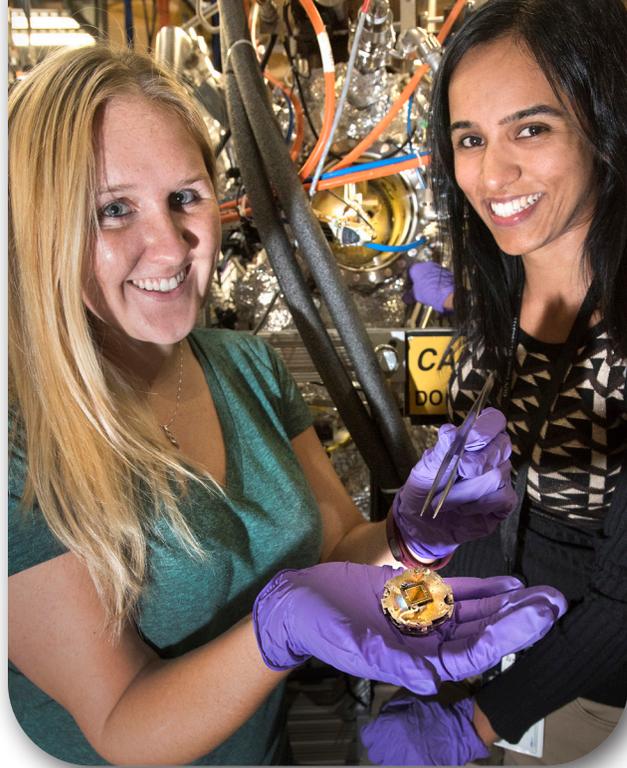
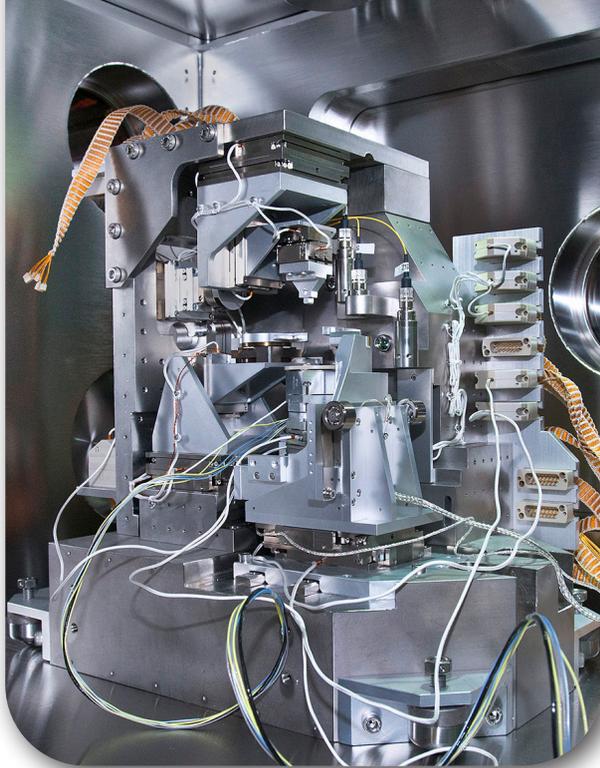
User Science

The first user arrived at NSLS-II in July 2015, and in the 2016 fiscal year the facility received almost 500 proposals for beam time and hosted 471 scientists across all beamlines, 7 of which are currently accepting general users. Another 9 beamlines are in commissioning, and these will all be accepting user proposals in September 2016. It will take an average of 6 months from first light to hosting first users at each beamline, during which time commissioning takes place.

In development are 12 more beamlines that will enter commissioning and operations between 2017 and 2018. The research and development efforts at NSLS-II have opened new possibilities for world-leading imaging capabilities. The Hard X-ray Nanoprobe beamline, for example, is home to a microscope that offers the best spatial resolution in the world, and was recently celebrated as one of the 10 best microscopy innovations of the year with a 2016 *Microscopy Today* Innovation Award and is a finalist for an R+D 100 award.

Beamlines accepting General Users:

- The **Hard X-ray Nanoprobe (HXN)** beamline hosted first users in Summer 2015 and offers a resolution of 15 nanometers with imaging capabilities including fluorescence, phase-contrast and spectroscopy. More advanced capabilities including nanodiffraction and fluorescence tomography under *in situ* sample environments are being commissioned now, with a goal of offering them to general users in early 2017.
- The **Submicron Resolution X-ray Spectroscopy (SRX)** beamline hosted first users in Summer 2015 and offers X-ray fluorescence imaging and XANES spectroscopy with submicron spatial resolution. X-ray fluorescence tomography and the high-resolution setup offering a beam size of less than 100 nanometers are now being commissioned, with the goal of offering them to general users in early 2017.
- The **Inelastic X-ray Scattering (IXS)** beamline hosted first users in Fall 2015 and offers an energy resolution of 1.3 meV. The beamline is optimized for inelastic X-ray scattering studies of vibrational dynamics in a broad range of material systems and next-generation analyzer optics are currently being developed.
- The **Coherent Hard X-ray Scattering (CHX)** beamline hosted first users in Spring 2016 and offers experimental capabilities for coherent scattering with best-in-class flux. CHX offers user capabilities for X-ray photon correlation spectroscopy in small-angle scattering for both transmission and grazing incidence geometries, and work is ongoing toward expanding all capabilities to wide-angle scattering.
- The **Coherent Soft X-ray Scattering 1 (CSX-1)** beamline hosted first users in Spring 2015 and provides coherent soft X-ray scattering with world-leading high-coherent flux. Current techniques include: X-ray photon correlation spectroscopy, scanning diffraction microscopy with 100 nanometer resolution, and coherent diffraction imaging.
- The **Coherent Soft X-ray Scattering 2 (CSX-2)** beamline hosted first users in Spring 2016 and currently offers the capability of *in situ* characterization of surface chemical processes under reaction conditions using ambient pressure X-ray photoelectron spectroscopy with an operating pressure of up to 10 Torr. The AP-PES endstation was built in partnership with Brookhaven's Center for Functional Nanomaterials. Soft X-ray absorption spectroscopy of powder and thin film samples is also available and *operando* reactor cells are currently in development.
- The **X-ray Powder Diffraction (XPD)** beamline hosted first users in Summer 2015 and enables X-ray diffraction with high photon flux for time-resolved and *in situ* experiments. XPD covers a great diversity of experiments in areas ranging from next generation batteries, catalysis, ultra-high temperature ceramics, structural nuclear materials, pharmaceutical drugs through high-temperature superconductors. Current techniques include 2D diffraction on polycrystalline materials, pair distribution function analysis, medium-angle X-ray scattering and modulation enhanced X-ray diffraction.



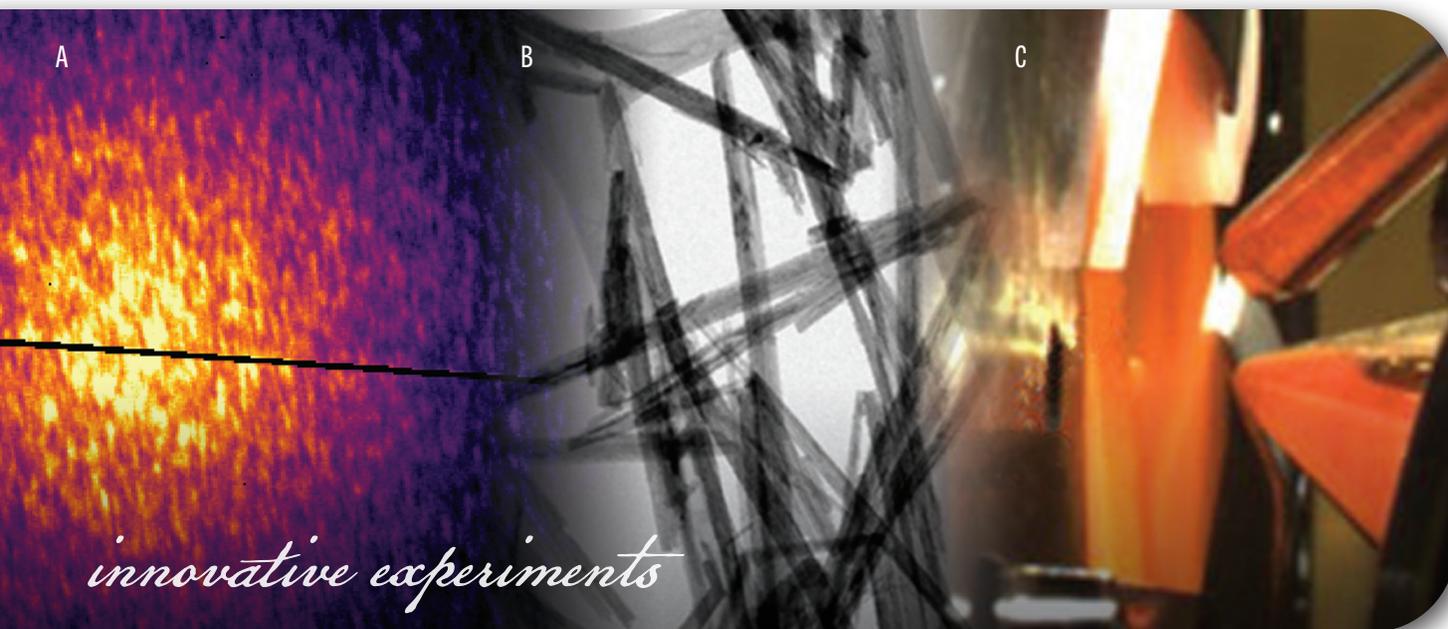
Commissioning:

- The **Life Science X-ray Scattering (LIX)** beamline took first light on November 16, 2015 and started solution scattering experiments in August 2016. Scanning micro-diffraction experiments will follow in the Fall 2016 cycle. LIX will host first users in Fall 2016.
- The **Frontier Microfocusing Macromolecular Crystallography (FMX)** beamline took first light on March 8, 2016. The technical commissioning work led to FMX taking its first diffraction dataset on July 16, and the beamline welcomed its first users for the scientific commissioning of microfocus cryo-crystallography in Summer 2016.
- The **Highly Automated Macromolecular Crystallography (AMX)** beamline took first light on March 8, 2016 simultaneously with its companion FMX beamline. Technical commissioning yielded focused beam and an initial set of diffraction images of a bacterial drug complex, a validating step towards scientific commissioning, which occurred in Summer 2016.
- The **Inner Shell Spectroscopy (ISS)** beamline took first light on April 5, 2016, has commissioned all essential components of the photon delivery system, and started science commissioning with first users in Summer 2016.
- The **In Situ and Resonant X-ray Studies (ISR)** beamline took first light on July 11, 2016 and began optics commissioning and vacuum conditioning in July 2016. Science commissioning with first users is anticipated to begin in Spring 2017.
- The **Electron Spectro-Microscopy (ESM)** beamline took first light on July 25, 2016 and is expected to host first users for scientific commissioning in Spring 2017.
- The **Complex Materials Scattering (CMS)** took first light on August 26, 2016 and is expected to host first users for scientific commissioning in Spring 2017.
- The **Tender Energy X-ray Absorption Spectroscopy (TES)** beamline took first light on August 17, 2016. This will begin the technical commissioning phase, with first users for science commissioning planned for Fall 2016.
- The **X-ray Footprinting for in Vitro and in Vivo Studies of Biological Macromolecules (XFP)** beamline took first light on July 11, 2016. First users for science commissioning are expected in Fall 2016.

The first three of these beamlines (LIX, FMX and AMX) were funded by the National Institutes of Health (the ABBIX project); the second three (ISS, ISR and ESM) are part of a DOE-BES MIE (the NEXT project); the next two (CMS and TES) are part of the BDN project and TES has support from partners at NSF Earth Sciences, BES Geosciences and the NASA Lars program; and the last, XFP, is a beamline built in partnership with Case Western Reserve University.

*world-leading
imaging capabilities*

Science Highlights



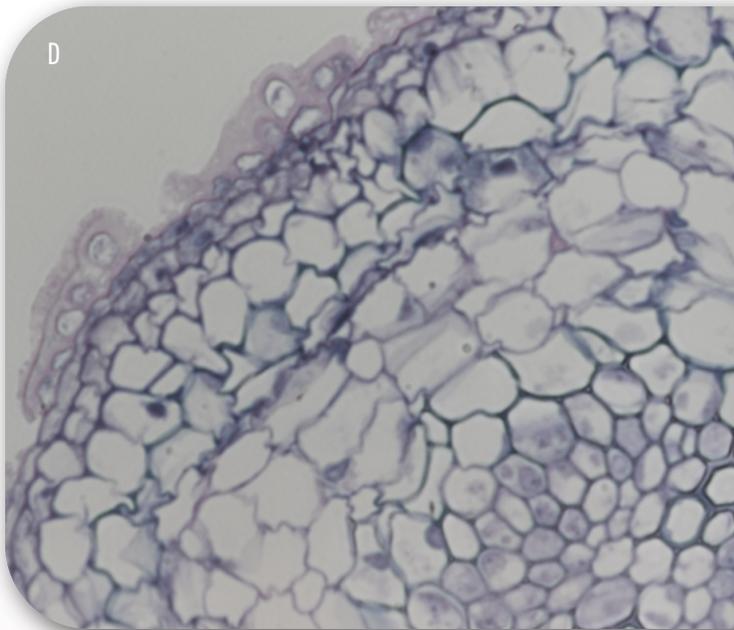
NSLS-II has hosted users at the top of their field as well as those new to the world of synchrotron science. In the first year of user operations, innovative experiments at NSLS-II beamlines have led to research published in premier journals that explores new experimental techniques and will lead to real world applications for energy solutions, industrial efficiency, and the improved health of humans and ecosystems.

4 A collaboration of researchers from Brookhaven National Lab and Stony Brook University completed a study describing molecular structural defects in silver hollandite nanorods (B) and how these defects affect the rods' electrochemical performance in fuel cells. The study showed that a seemingly small change in silver content could lead to a 7-fold improvement in performance. Researchers studied hollandites – a class of manganese oxides with a tunnel structure that provides a framework for insertion and de-insertion of ions and small molecules – using local techniques (atomic imaging, electron diffraction, electron energy-loss spectroscopy) and bulk techniques (synchrotron-based X-ray diffraction, thermogravimetric analysis). X-ray diffraction was completed at the **X-ray Powder Diffraction** beamline, and this work was featured in *ACS Nano*, the first premier publication resulting from an NSLS-II study.

A study done at the **Coherent Soft X-ray 1** beamline examined a cuprate – a class of materials famous for becoming superconducting at high temperatures – in a brand-new way. Researchers led by members

of Brookhaven Lab's Condensed matter Physics & Material Science department used X-ray photon correlation spectroscopy to test for possible slow charge-density wave fluctuations in LBCO 1/8, a cuprate with the strongest charge-density wave signal. The high flux and coherent nature of the beam allowed them to measure the speckle of the diffraction pattern from the charge "stripes" (A) in the material, proving that they are frozen in time, a critical piece of information in understanding how charge order in the cuprates is related to their ability to superconduct. The frozen nature of the "stripes" appears to rule out an entire class of theories for high-temperature superconductivity and is an important step in our understanding of these fascinating materials.

A study of the ecotoxicity of a diesel fuel additive used in the European Union to decrease air pollution and increase fuel efficiency, cerium dioxide (CeO_2), may help to determine how this material affects human health and the natural environment, and how it could possibly be transferred through the food web. Cerium dioxide may be directly deposited onto



soils via emissions from diesel-powered vehicles, but little is known about its impact. Researchers used X-ray fluorescence imaging and phase-contrast imaging at the **Hard X-ray Nanoprobe** beamline, which delivers world-leading spatial resolution, to correlate trace elements with cell structures and substructures. The high sensitivity and extreme resolution of HXN showed for the first time that the nanoparticles do indeed make it into plant cells and helped determine the mechanism by which CeO_2 nanoparticles are taken up and transported in the cells of tomato roots (D).

A paper published in the *Journal of Physical Chemistry* explored findings from the **Coherent Soft X-ray 2** beamline, in which ultrathin two-dimensional nanoporous silicates (C) were found to inhibit oxidation while staying essentially intact, while thicker aluminosilicates did not. Zeolite nanosheets were deposited and on top of that bilayer silicate and aluminosilicate films were grown onto a ruthenium single crystal surface, which researchers then investigated using synchrotron-based ambient pressure X-ray photoelectron spectroscopy. This research, which used capabilities built in partnership with Brookhaven's Center for Functional Nanomaterials, could lead to promising applications in the development of ultrathin anti-corrosion coatings useful for industry.

real world applications

Partnership with CFN

The Center for Functional Nanomaterials (CFN) is a cutting-edge facility at Brookhaven and also a path to bring users to NSLS-II.

The synergy between the two institutions led to a partnership in which CFN provides equipment and expertise for 4 world-class beamlines, including:

- the ambient pressure photoelectron spectroscopy end station at the Coherent Soft X-ray Scattering beamline
- the in-vacuum sample chamber, wide-angle X-ray scattering detector, and hardware for enhancing throughput at the Complex Materials Scattering beamline
- the X-ray photoemission electron microscope at the Electron Micro-Spectroscopy beamline
- the medium-angle area detector at the Soft Matter Interfaces beamlines

Looking Forward

In the coming months, NSLS-II is on track to increase beam current, continue beamline development including at least one new state-of-the-art beamline, and grow the user community.

By the end of fiscal year 2017, the accelerator group will increase operating current in the storage ring to 300 milliamps, and user growth will continue with a goal of hosting 1000 users.

Beamline development continues with an aggressive schedule over the next 6 fiscal years:

- By the end of 2017, 17 beamlines will be fully operational for visiting researchers and another 5 will be in technical commissioning.
- By the end of 2018, 26 beamlines will be in service, with 1 more undergoing technical commissioning.
- Beginning in 2019, 28 beamlines will be fully operational with another coming online by the end of 2020.

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October 2016